Review Article

Role of the anterolateral complex in rotatory instability of the anterior cruciate ligament deficient knee

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Abstract: The anterolateral complex (ALC) of the knee plays an important role in rotatory knee stability, especially in anterior cruciate ligament (ACL)-deficient patients. There is considerable awareness of anterolateral rotatory instability secondary to reported high failure rates after ACL reconstruction. As such, there has been a renewed interest in lateral extra-articular reconstruction procedures to stabilize the ALC. The concept of lateral extra-articular tenodesis (EAT) as the sole treatment of ACL injuries was popular in the 1970s, but fell out of favor due to unacceptably poor long-term outcomes. However, as greater understanding of rotatory knee instability has evolved, lateral stabilization procedures similar to those described in the 1970s have emerged to augment ACL reconstruction. These additional soft tissue techniques are not without risk, as many studies have demonstrated knee over-constraint after these procedures. Therefore, it is prudent to take an individualized approach to ACL reconstruction and to assess the value of additional soft tissue procedures in the face of persistent rotatory laxity. This review will address the role of the ALC in rotatory knee injury, the difficulty in diagnosing these injuries, and provide an objective review of additional stabilizing procedures after ACL reconstruction.

Keywords: Anterolateral ligament (ALL); anterolateral complex (ALC); rotatory knee instability; pivot shift; anterior cruciate ligament (ACL)

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Introduction

Injuries to the anterior cruciate ligament (ACL) alter the kinematics of the tibiofemoral joint significantly. Failure to restore the native knee biomechanics can cause long-term functional impairment and degenerative changes (1,2). The goals of ACL reconstruction are to re-establish the physiological anterior translation and internal rotation of the tibia relative to the femur without over-constraining the knee joint.

Rotatory knee laxity plays a crucial role in ACL injuries and treatment algorithms (3). Increased rotatory knee laxity, assessed most commonly with the pivot shift test, indicates damage to the ACL and anterolateral knee structures (4). Although the clinical results of the ACL reconstruction are usually excellent (5), there is a subgroup of patients that continues to experience residual rotatory instability. This rotatory laxity is a matter of concern among surgeons, who ascribe this failure to overlooked associated injuries, different bony morphologic patterns, or inadequate reproduction of the native ACL anatomical footprints (6). This has led physicians to seek out other causes and treatments of anterolateral rotatory knee laxity.

The ACL is considered the primary restraint to anterior and rotatory knee stability, including both internal and external rotation, but there are many secondary stabilizers that play an important role. Notably, the posterior horn of the medial meniscus and the lateral meniscus provide an important contribution. Additionally, the anterolateral structures of the knee contribute to rotatory knee stability (7). Recently, a ligamentous structure in the lateral aspect of the knee called the anterolateral ligament (ALL) has been described. Some authors advocated its role in supplementing the ACL in controlling rotational laxity and internal rotation (8).

Additional stabilizing procedures during ACL reconstruction have emerged to address this residual rotatory laxity. These lateral extra-articular tenodesis (EAT) procedures have been biomechanically shown to decrease internal tibial rotation; conversely, they have also been shown to over-constrain the knee (9). Recently, anatomic ALL-specific reconstructions have emerged with conflicting results.

These contrasting findings of the ALL, and emergence of supplemental soft tissue procedures, have triggered a debate about its precise anatomical position, its biomechanical role and the need for additional surgical procedures.

Anatomy

In the earliest accounts of the ALL, Paul Segond in 1879 described a "pearly, resistant, fibrous band" on the anterolateral aspect of the knee that caused an avulsion fracture during forced knee internal rotation, now known as the "Segond fracture" (10). However, this structure was not mentioned again in anatomic descriptions or textbooks for nearly another century.

Ambiguous anatomic descriptions of this capsular thickening ensued, including "mid-third lateral capsular ligament" (11-13), "capsule-osseous layer of the iliotibial band (ITB)" (14,15), and "anterior oblique band" (16). Recently, cadaveric studies have expanded on this work and anatomically described the anterolateral structures of the knee, including this so-called "ALL" (14,15,17).

In the study by Claes *et al.* (17), the ALL was described as a distinct ligamentous structure at the anterolateral side of the knee joint, clearly distinguishable from the capsule, the ITB, and the lateral collateral ligament (LCL). Since this study, various attempts have been made to localize the femoral and tibial insertion of the ALL as well as its fiber orientation, adhesion to the capsule and the lateral meniscus.

Multiple attachment sites of the proximal insertion site of the ALL have since been described. Claes *et al.* (17) described a structure that originates from the lateral femoral epicondyle, posterior and proximal to the insertion of the popliteus, and anterior to the femoral insertion of the LCL. Soon after this, a study utilizing fresh-frozen cadavers demonstrated the femoral attachment site to be 9 mm proximal to the lateral epicondyle (18). Another study detailed the femoral attachment to be 3.5 mm distal and 2.2 mm anterior to the attachment of the LCL (19).

Most authors agree that the distal insertion is located midway between the center of Gerdy's tubercle and the anterior margin of the fibular head, approximately 4.5 mm from the most distal articular portion of the tibia (17-19).

Other ongoing concerns with the ALL are its relation with the knee joint capsule and the lateral meniscus. Some authors (17,18,20) describe the ALL as a ligament that is distinguishable from the capsule, while others (21-23) denote the ALL is unequivocally a thickening of the knee joint capsule.

Additionally, histological analysis of the ALL remains an unresolved and controversial issue. Vincent *et al.* (24) documented wavy collagenous fibers with a parallel orientation in the core of the capsule, suggesting the presence of a distinct ligamentous structure. However, Dombrowski *et al.* (25) did identify capsular thickening in only 30% of specimens with "ligament-like" characteristics.

ALL prevalence

Although in some cadaveric studies the ALL was identified in 80–100% of the specimens (17-19,23,24), other investigators have reported it is possible to clearly identify it in only 30–50% of the samples (20,22,26). Additionally, a recent study reported that none of the specimens showed a clear lateral capsular ligament (25) (*Figure 1*).

This ambiguity in anatomic findings may be due to various specimen preservation techniques, a wide age range of the specimens, different anatomic dissection techniques, and inconsistent terminology. The cadaveric studies utilized different methods of preservation including embalmed and fresh-frozen specimens, which can alter the integrity of small structures, especially in the anterolateral complex (ALC). Interestingly, some authors have highlighted the discovery of the ALL with their dissection techniques by internally rotating the tibia and removing any surrounding tissue without tension (23,27). With such ambiguity, the anterolateral aspect of the knee, including the ALL, ITB,

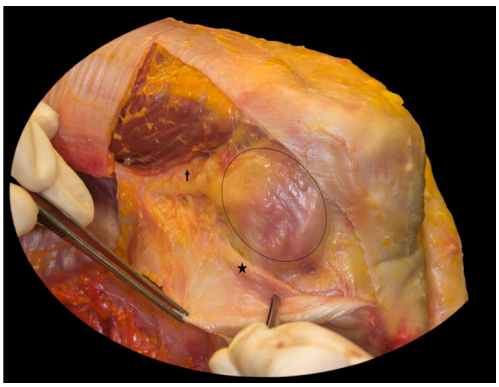

Figure 1 Anatomic dissection of lateral knee. An anatomic dissection of the lateral aspect of the knee, with the ITB cut and reflected posteriorly (within forceps). After removal of ITB, the Kaplan fibers (arrow) can be seen running from the superficial ITB, which play a role in rotatory knee stability. The posterior fibers of the ITB (star) blend with the capsulo-osseous layer and the deep ITB to insert in the area around Gerdy's tubercle. The lateral knee capsule (dotted circle) is clearly identified without a distinguishable ALL visualized. ITB, iliotibial band; ALL, anterolateral ligament.

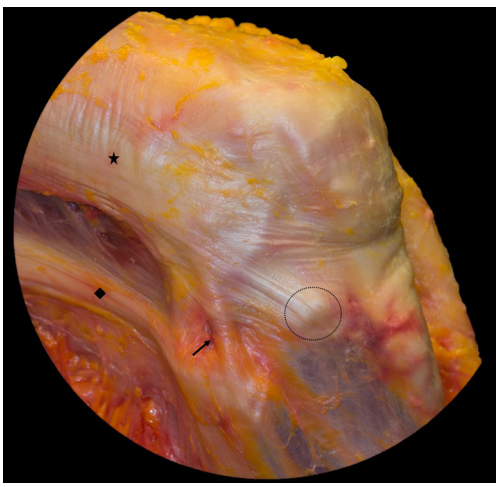

Figure 2 Anatomic dissection of superficial lateral knee. An anatomic dissection revealing the superficial layer of the lateral knee. An identifiable ITB (star), biceps femoris (diamond), and lateral collateral ligament (arrow) are appreciated. Additionally, Gerdy's tubercle (dashed circle) is well visualized. However, there is no identifiable ALL visualized on dissection. ITB, iliotibial band; LCL, lateral collateral ligament; ALL, anterolateral ligament.

and capsulo-osseous layer of the ITB, will be collectively defined as the ALC (*Figure 2*). Consequently, biomechanical studies have suggested all the structures of the ALC contribute to rotatory knee stability as a whole unit, rather than as individual ligaments (28,29), further confirming the complex as a collective unit.

Imaging

Proper imaging modalities to diagnose injury to the ACL and concomitant lateral structures are paramount for treatment purposes and patient outcomes. Anatomy of these structures has been well documented throughout the years, with the only current controversy regarding the existence of an ALL. While the diagnosis of ACL injuries has been well described and implemented, radiographic determination of ALC injuries is more complex and controversial. To date, imaging modalities to detect ALC injuries include x-ray, ultrasound, and magnetic resonance imaging (MRI).

X-ray

Highly regarded as a pathognomonic sign of ACL injury, the Segond fracture is a cortical avulsion off the anterolateral aspect of the tibia seen in around 1% of ACL injuries. This fracture results from excessive internal rotation and varus torque to the knee (10). This fleck of bone can be visualized an AP views of the knee. In 1979, Woods *et al.* (30) suggested this fleck of bone represented an avulsion fracture of the lateral capsular ligament, indicating a high-grade ACL injury. The authors also postulated this fracture represented a repairable injury to the lateral knee capsule and proceeded with EAT on all patients who presented with this fracture (30). Other studies validated this finding, concluding the Segond fracture was in fact an avulsion of the lateral capsular ligament and represented injury to the ACL (31,32). Most recently, this avulsion fracture has been intimately associated with the ALL (33). Although the exact etiology of the Segond fracture remains controversial, studies concur this avulsion fracture represents a rotatory knee injury mechanism and ACL tear.

Ultrasound

Ultrasound can be a powerful and relatively inexpensive imaging modality to assess the supporting structures of the knee. Although the knee anatomy is complex, ultrasound has been demonstrated to produce an accurate and detailed evaluation of knee anatomic structures, including the lateral knee complex (34). However, conflicting studies have emerged describing the ability of ultrasound to detect

the ALL.

Although challenging, one study demonstrated the ability to distinguish its femoral and tibial attachment sites when the knee was brought into flexion and internal rotation (35). A recent cadaveric study found the tibial portion of the ALL could be distinguished on all specimens, but the meniscal and femoral attachments could only be identified in <50% of the specimens (36). Another study utilized real-time virtual ultrasonography and visualized a distinguishable ALL in 7 of 9 subjects (36).

On the contrary, ultrasound was utilized on ten cadaveric knees and found a large discrepancy between the ultrasonographic and dissection findings. The authors found a mean ALL length on ultrasound and dissection to be 10.9 mm (range, 7.9–15.8 mm) and 12.5 mm (range, 3.2–19.3 mm), respectively. They concluded ultrasound was unable to reliably identify the ALL attachment sites, and it is possible that ALL could be a thickened band of fascia rather than a true ligament. Additionally, they stated that distinguishing the ALL from the posterior ITB and the anterolateral capsule was challenging (37). Another study utilized ultrasound to identify, in great detail, the lateral structures of the knee, but failed to identify an ALL in any subject (38). In summary, ultrasound can be a useful and cheap alternative to detect injury to the ALC, but distinguishing injury to individual structures is more problematic and difficult.

MRI

MRIs are routinely obtained on patients with a suspected ACL injury, and are highly sensitive and specific for an ACL tear (39). However, the complexity of the ALC, and specifically identifying individual structures such as the ALL, can decrease the utility of MRI.

Some have reported that MRI yields accurate visualization of all lateral knee structures, including the ITB and LCL (12,16). A retrospective review of ACL injuries demonstrated 100% visualization of the ALL, but poor intra-observer and inter-observer reliability in assessing injuries to the ALL. They concluded MRI has poor reliability in distinguishing between a torn and intact ALL (40). Another group compared MRI results with cadaveric specimens, and was able to visualize the ALL in all specimens (41).

Conversely, a separate study utilizing cadavers to compare anatomic findings with MRI findings demonstrated variable thickness of the lateral capsule without a discernable ligamentous structure (25). A fresh-frozen cadaveric study revealed morphologic variations in the ALC anatomy, with the inability to detect an ALL (25). A study from our own research group attempted to identify and grade ALC injuries in ACL-injured patients, but found only 51% of patients had a discrete injury to their ALC and less than 4% had complete disruption (42). Overall, MRI does have a utility in detecting injuries to the ALC, but delineating injuries to specific structures will require further research.

Rotatory knee stability

Rotatory knee stability involves the combined efforts of soft tissue tensioning and bony morphology. Recently, biomechanical studies have demonstrated the importance of the ALC on internal tibial rotatory knee stability, and have attempted to describe the various roles of the individual components. The ITB has been shown to make a significant contribution, especially at higher flexion angles. Tibial internal rotation is increased with sectioning of the Kaplan fibers and capsulo-osseous layer (43). There is little contribution of the ALL, with no increase in tibial internal rotation after sectioning of the ALL with an intact ITB (43).

Several robotic studies have found an increase in tibia internal rotation in ALL-deficient knees, with the greatest difference seen at 60 degrees of knee flexion (44,45). However, during a simulated pivot shift test, one study only found a small difference in tibia internal rotation after the ALL was sectioned (44); a similar study demonstrated a maximum difference of 3.3 degrees with tibial internal rotation at 45 degrees of knee flexion between ALL-deficient and ALL-intact knees. At lower knee flexion angles where the clinical pivot shift occurs, the contribution of the ALL became negligible (46). These studies indicate the ALC, especially the ITB, contributes to rotatory knee stability, but the role of the ALL can be considered minor.

Pivot shift

The pivot shift test assesses the complex kinematic motions of the knee, including anterolateral rotatory laxity, and is the most specific test for detecting ACL injury (*Figure 3*) (48). Several studies have indicated that the degree of pivot shift is correlated with return to play, patient satisfaction, overall knee function, and subjective knee stability after ACL reconstruction (2,49). As such, the goal of ACL reconstruction is to restore the normal biomechanics of the

Figure 3 User interface of the iPad PIVOT App during a quantitative pivot shift. The quantitative pivot shift is standardized by utilizing the PIVOT application. The video of the pivot shift is in the box on the top left. The tracking process, with the help of markers attached to specific landmarks on the knee as previously described, is shown on the bottom right (47). The graph displays a sudden decrease in femoral anterior translation, which is the point of tibia reduction. Reprinted from (47) with permission of Springer.

knee and minimize or eliminate the rotatory knee laxity that leads to a pivot shift. However, multiple variables contribute to this complex motion, including the ACL, capsule, lateral and medial menisci, bony morphology, and ligamentous knee laxity (50-54).

As described earlier, the ALC has been shown to provide secondary restraint to knee internal rotation and rotatory knee stability. Acute injuries of the ALC, as seen on MR images, were shown to be risk factors for high grade pivot shift (42,55). A recent biomechanical cadaveric study indicated the influence of the ALC on knee internal rotation and rotatory knee laxity increases as knee flexion increases beyond 30 degrees (28).

However, controversy still remains regarding the influence of the ALL versus the entire ALC. One study demonstrated the influence of the ALL on internal rotation at flexion angles greater than 30 degrees exceeded the contribution of the ACL (45). The ALL was also shown to be an important secondary stabilizer to knee internal rotation and rotatory knee laxity during knee flexion in ACL-deficient knees (46,56,57). Conversely, a cadaveric biomechanical study determined lesions of the ALL with an intact ITB did not influence rotatory knee laxity in an ACL-deficient knee (58). Another study showed the ALL played only a minor role in restraining internal rotation during knee flexion, while the ITB was the major secondary stabilizer to internal rotation at 30 and 90 degrees of knee flexion (43).

The prior studies demonstrated contributions from the ALL at knee flexion angles greater than 30 degrees. The clinical pivot shift tests rotatory knee stability at knee flexion angles less than 30 degrees. Therefore, the contribution of the ALC to the clinical pivot shift remains unclear. In fact, one study described negligible contributions from the ALL beyond the physiologic limits of motion of the knee (59). Another study demonstrated that at 30 degrees of knee flexion, there was no difference in the in-situ forces between the ACL and ALC during a simulated pivot shift test, indicating the ALC plays a limited role in the clinical pivot shift (28). A recent clinical study even demonstrated an 8.4% residual pivot shift after combined ACL and ALL reconstruction (60), suggesting that other soft tissue restraints besides the ALL and ACL may be present at physiologic ranges of tibial translation. As such, surgeons should utilize this knowledge when contemplating surgical options after an ACL tear, especially additional soft-tissue procedures.

Surgical options

The concept of surgical fixation to control anterolateral knee rotation with EAT procedures has been present for decades. In the 1970's, surgeons utilized various EAT procedures as the sole surgical operation to address ACL-deficient knees (61). However, two landmark studies emerged in the late 1970's that demonstrated poor long-term outcomes with EAT alone for ACL-deficient knees (62,63). It was determined the grafts stretched out and only provided temporary stability. As such, the paradigm shifted to intra-articular ACL reconstruction alone, especially after studies emerged demonstrating no difference in functional outcomes between ACL reconstruction and ACL reconstruction with the addition of EAT procedures (64).

Lateral EAT

Recently, renewed interest in EAT procedures have emerged in order to address injury to the ALC and improve rotatory control of the knee (65). Initial studies produced promising results. A cadaveric biomechanical study demonstrated EAT significantly decreased the forces on the ACL by 43% (66). The addition of EAT to ACL reconstruction can be an effective procedure, and showed minimal complications at 2-year follow-up (60). Marcacci *et al.* reported long-term

outcomes on patients treated with hamstring autograft ACL reconstruction and lateral tenodesis. They demonstrated only 2 (out of 54) patients had greater than 5 mm side-to-side difference in anterior-posterior laxity, and 90% of the patients having good or excellent IKDC scores (67). A long-term follow-up study determined the addition of EAT had improved knee stability, no increased risk of osteoarthritis, and a decreased rate of ACL failure (68). Other studies have demonstrated no benefit to the addition of EAT. A recent prospective, randomized control trial demonstrated no significant benefits to patient outcomes with the addition of EAT to ACL reconstruction (69).

ALL reconstruction

As the renewed interest in the ALL emerged, numerous studies appeared that focused on anatomic ALL reconstruction. Due to the multiple anatomic ALL configurations documented, one study attempted to standardize the anatomic landmarks by utilizing cadaveric specimens to document radiographic landmarks for ALL reconstruction (70). A robotic cadaveric study demonstrated anatomic ALL reconstruction significantly improved rotatory knee instability after ACL reconstruction (44). On the other hand, a separate study demonstrated anatomic ALL reconstruction did not reduce rotational knee laxity. This study suggested the ALL becomes functional at unphysiologic knee motions and only engages the tibia once tibial displacement extends beyond the physiologic knee motion of an ACL-intact knee. The authors concluded that EAT procedures may diminish anterior and rotational knee laxity, but ALL reconstruction is not necessarily needed in a well-functioning knee (56).

It is important to note that both EAT procedures and ALL reconstruction have been demonstrated to potentially over-constrain the knee. A cadaveric study concluded ALL augmentation significantly reduced rotatory knee laxity, but resulted in over-constraint of the knee at all flexion angles (9). The addition of EAT has also been shown to cause excess external rotation as compared to normal or ACL reconstructed knees (66), potentially leading to unfavorable long-term outcomes.

Conclusions

The ALC, which includes the ITB, with its deep and capsulo-osseous layer, Kaplan fibers, lateral capsule, and mid third capsular ligament plays an important role in rotatory knee stability. After an ACL injury, recognition of concurrent injuries to the ALC of the knee is important to assess rotatory knee instability. Apart from soft tissue restraints, factors such as bone morphology, muscular control, proprioception and hypermobility have an impact on rotatory knee stability. It is, therefore, crucial to consider all aspects and offer a tailored surgery to each individual patient.

Recently described surgical approaches to address ALC injuries are still controversial with conflicting results. Although lacking evidence in larger patient cohorts, these additional surgical procedures may be useful in a selected subset of patients. Future research into these procedures is warranted, along with an individualized approach to patients with ALC injuries and injuries to the ACL.

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Footnote

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